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NAVAL AEROSPACE MEDICAL INSTITUTE
NAVAL AEROSPACE MEDICAL CENTER
PENSACOLA, FLORIDA 32512

SUMMARY PAGE

THE PROBLEM

To measure and compare normal subjects and persons with severe or complete loss of otolith function in the amount of ocular counterroll associated with several tilt angles as a function of g-loading.

FINDINGS

A group of six normal subjects manifested a compensatory eye roll which increased as a direct and essentially linear function of the component of the gravitoinertial force acting laterally upon the subject. This increase in response was not observed in the five deaf subjects with severe or complete bilateral loss of their vestibular organs. These findings confirmed similar results found by other authors using other measuring techniques which show that the reflex eye movement is dependent upon and limited to the magnitude of the gravitoinertial stimulus (within the range used) when the otolitho-ocular system is functioning normally. However, when this function is impaired or lost, the magnitude of the compensatory eye roll is limited to that manifested at 1 g and possibly to nonotolithic contributions. These findings offer means for differentiation between otolithic defective individuals and "normal" persons who exhibit little counter-rolling.

INTRODUCTION

The study of otolith activity in man is dependent upon a limited few overt indicators which vary in their specificity and measurability (1, 2, 4, 6, 9, 10, 11, 13, 15). At the present time, ocular counterrolling represents the best objective means to explore the response characteristics of the otolith organs at the reflex level. The usefulness of this external indicator has been increased with the development of a highly precise photographic measuring technique and testing methods which minimize the influence of extra-labyrinthine factors upon ocular torsion (6-8, 12). The precision afforded by this procedure reduces the need for using centrifugal force to magnify the response, and thus eases the difficulties in measurement of ocular roll. However, centrifugation may still offer a means by these measurements of exploring etiological differences between small amounts of ocular counterrolling manifested by apparently normal subjects and by those persons with severe bilateral labyrinthine defects.

Woellner and Graybiel have demonstrated that ocular counterrolling as reflected by the relative movement of two silk sutures in the conjunctiva was increased substantially in direct response to the amount of centrifugation (lateral g force) among five normal subjects, but the procedure failed to produce similar results for two totally deaf subjects with labyrinthine defects (16). Colenbrander recorded changes in the position of the subject's blind spot which indicated increases in magnitude of normal counterrolling as well as a steepening of the typical "S" shape response curve among his normal subjects in progressing from 1.0 to 1.5 to 2.0 resultant g (1).

The purpose of the present study was to explore further, by the photographic method, counterrolling as a function of hypergravic stimulation in six normal subjects and in five deaf subjects with established functional losses of the semicircular canals and otolith organs.

PROCEDURE

SUBJECTS

Six healthy young male medical students volunteered as subjects for this study during their Navy officer clerkship training at Pensacola. Each demonstrated substantial ocular counterrolling as measured by the standard photographic technique (6), and was free of any defect, disease, or disorder.

Five totally deaf men with complete or severe bilateral functional loss of the cupular and macular organs were chosen from a group of instructors and students at Gallaudet College to serve as the labyrinthine-defective comparison group of subjects. Their clinical résumé, which includes the results of measuring appropriate eye movement responses to thermal stimulation (5) and static body tilts (7), is given in Table I.

Table I

Clinical Findings in Five Deaf Subjects with Bilateral Labyrinthine Defects

		Deafness		Hearing		Caloric Response*		Date	Counterrolling
Subj.	Age	Etiology	Age of Onset (yrs)	R	L	R	L	Tested	Index+
GR	48	Mastoiditis	12	Nil	160 dB	Negl.	Negl.	1962	60
GU	22	Meningitis	4 - 1/2	$\geq$145 dB	$\geq$145 dB	Negl.	Negl.	1962	89
MY	26	Meningitis	8	None	None	None	None	1962	99
ST	21	Meningitis	12 - 1/2	$\geq$130 dB	$\geq$130 dB	Negl.	Negl.	1962	47
ZA	21	Meningitis	3 - 1/2	$\geq$135 dB	$\geq$130 dB	None	None	1962	85

*Negligible or no observable nystagmus when tympanum irrigated with water at a temperature of 11°C or less.
+Calculated as one-half the sum of the eye roll measured in minutes of arc at the 50° rightward and leftward tilt positions.

APPARATUS

A tilt chair was mounted on the arm of the Pensacola human centrifuge, 15 feet 10 inches from the center of rotation, and was completely covered by a light-tight metal enclosure. The chair was so constructed that it could be tilted leftward or rightward up to 90° by hydraulic power or held fixed in its upright position. A gimbal ring support allowed the chair to be rotated completely about its yaw axis, which coincided with the subject's longitudinal body axis, for pre-positioning the subject to face in or 180° counter to the direction of centrifuge rotation for effective rightward or leftward tilting, respectively. A hollow rubber appliance, filled with fine particles described in detail previously (13), was used as the chair's inner liner. With proper manipulation this liner could be made to conform closely to the subject's torso, neck, and head, and when evacuated, it became a rigid, form-fitting support. The head portion of the appliance was completely encased in a large helmet which was in turn attached to the tilt chair. Additional straps were used to secure the appliance as well as the subject's legs and feet to the chair.

A 35-mm camera and electronic strobe system fully described elsewhere (6-8, 12) was bolted to the tilt-chair supporting frame. A biteboard extended from the camera base, and this entire assembly could be moved along its three principal axes for proper imaging of the subject's eye being photographed. The camera was equipped for remote firing by the experimenter from within the room at the center of the centrifuge. Voice and buzzer (hand vibrator) communication systems were available between the subject and experimenter as well as between the experimenter and the centrifuge external control room.

METHOD

1. Tilt of the Subject With Respect to the Gravitational Vertical

The subject was positioned in the tilt chair and properly secured with the supportive appliance and straps. The camera/strobe apparatus with its biteboard attachment was bolted immediately in front of the subject on the chair frame. The biteboard was inserted in the subject's mouth, and he bit firmly into the temporarily softened dental material deposited on it. The camera was then racked into its proper position to focus upon the subject's right eye; his left eye was covered with an opaque patch. One drop of pilocarpine hydrochloride 1 per cent was instilled in the eye being recorded to reduce the over-all size and physiological oscillations of its pupil (15), important factors in the subsequent analysis of the film records.

During this phase of the experiment the observer conducted the test within the metal enclosure. While the subject was in the upright position, several photographic recordings were made. The mean recorded eye position measured among these recordings served as the basis for computing eye roll deviation found for the various tilt positions. One recording was used as the reference for comparing all other recordings by the method of superimposing two projected images, as described elsewhere (6).

The chair was first tilted slowly from upright either in rightward (+) or leftward (-) direction (randomized among subjects) and according to the following sequence: 25°, 50°, 58°, 63°. One recording was made at each of these tilt positions. At 63° a second recording was made before initiating the same tilt procedure but in the descending order of the degree of tilt in returning to upright; passing through upright the same ascending-descending tilt order was repeated in the opposite quadrant. This procedure was continued until at least three recordings had been made at each of the eight tilt positions and upright.

2. Tilt of the Gravitoinertial Vertical with Respect to the Upright Subject

Immediately following the static test of counterrolling and without removing the subject from the chair, the chair was rigidly fixed in its upright position. The observer moved to the central room of the centrifuge where controls were provided for firing the camera remotely and for communicating with the subject. The centrifuge was rotated slowly (within approximately 60 seconds) in the counterclockwise direction up to the velocity required to change the gravitoinertial upright in the same amounts (25°, 50°, 58°, 63°) and in the same sequential order rightward or leftward as in the static testing. Calculation of the gravitoinertial vector was based upon the radial distance from the axis of rotation to the center of the subject's head. Thus the essential difference between the static and dynamic forms of tilt was the difference (Δ) between the magnitude of the gravitational and gravitoinertial force which increased as a direct function of apparent tilt (displacement of gravitoinertial force vector) during rotation. Accuracy in the rate of rotation was maintained within plus or minus 1 per cent. The subject faced forward in the direction of rotation for effective rightward "tilting" and was turned 180° to travel backward along the path of rotation for leftward "tilting." The order of tilt direction was selected at random among the subjects. After slowly accelerating to each desired velocity, a 60-second delay was timed before the first photographic recording was made. As in the static phase, the test ended when the eye was photographed at least three times at each ϕ, the angle formed between the gravitational and gravitoinertial force vectors.

RESULTS

The results are summarized in Figure 1. Mean counterrolling data in minutes of arc of the two groups of subjects are plotted as a function of tilt angle in degrees with respect to the gravitational (closed circles) and the gravitoinertial upright (open circles). Individual counterrolling data were similar to those representing the group data, but in some instances, a given subject's responses were substantially more variable than the average. This is to be expected with limited eye recordings at each position since the eye is physiologically active and may be photographed while it is undergoing an occasional yet considerable spontaneous torsional shift (6). To reduce the effect of this influence which would be expected to occur in opposite directions at random among subjects, the results of the six normal as well as the five labyrinthine-defective subjects were averaged and compared as groups.

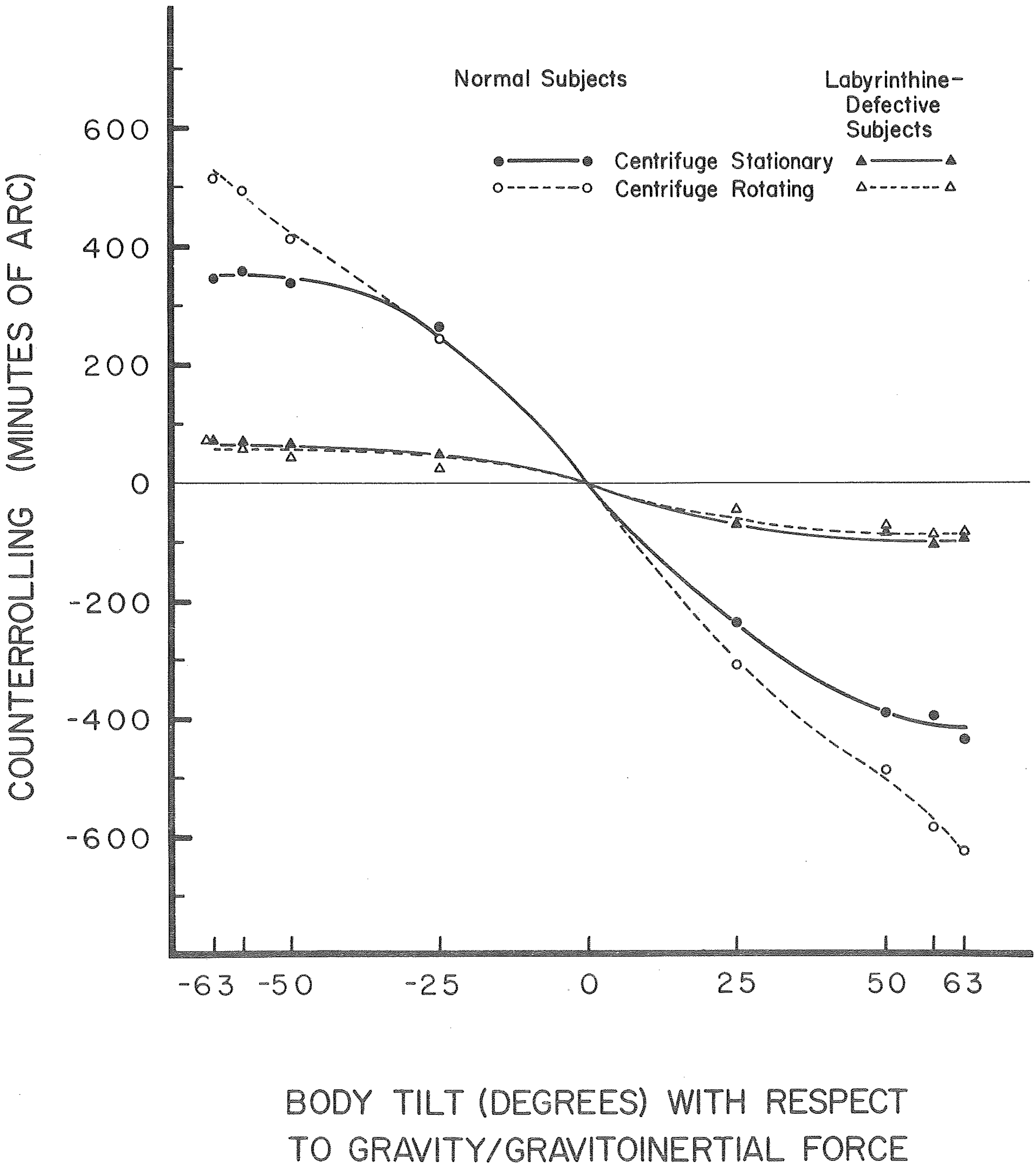

Figure 1

Counterrolling of Normal and Labyrinthine-Defective Subject Groups as a Function of Body Tilt with Respect to Gravitational or Gravitoinertial Force

The two curves representing the data of the normal group tested under the static and dynamic conditions appear to be nearly coincident at the smallest angle of tilt (Figure 1). With greater tilt angles in both the right and left directions, the curves become more and more disparate, revealing the effect upon ocular counterrolling of the ever-increasing amount of centrifugal force added to that of gravity. It is impossible to determine a direct relationship between counterrolling and magnitude of the inertial force since the angle, and, therefore, direction of the applied stimulus relative to the otolith organs were also varied. As suggested by Woellner and Graybiel (16), an approximation of the combined effect of magnitude and direction is possible by considering only the inertial force component acting sagittally and perpendicular to the subject's long axis. The intensity of this laterally directed force equals, under the static condition, the sine of the angle (ϕ) formed between the body axis and the gravitational upright, and under the dynamic conditions, the product of the gravitoinertial force (GIF) and the cosine of the angle (ϕ) formed between the body axis and the gravitoinertial upright. The difference between these values represents the difference ($\Delta \underline{g}$) in otolithic shear force generated by the two test conditions, centrifugation and tilting:

$$\Delta \underline{g} = \text{GIF} \cos \phi - \sin \phi$$

Figure 2 shows the linear relationship found in normals between the change in ocular counterrolling (Δ CR) as a function of the change in shear force ($\Delta \underline{g}$). The data of Woellner and Graybiel were recalculated by this format and revealed remarkable agreement with our data (Figure 2) even though the two groups of normal subjects differed in their basic counterrolling response levels.

The results from the labyrinthine-defective group of subjects are also presented in Figure 1. These subjects, in contrast to the normals, revealed no apparent difference in counterrolling measured under the dynamic and static test conditions.

DISCUSSION

The counterrolling response to static tilt (centrifuge stationary) shown in Figure 1 is typical of normal subjects; under these test conditions, eye roll compensation is greatest between upright and 25°, less between 25° and 50°, and tends to reach a limit around 60°. This pattern of response changes dramatically when the magnitude of the resultant force is increased as a byproduct of the centrifugation required to effect an apparent tilt with the subject maintained in alignment with gravity. At 25° of tilt under dynamic conditions, with only a slight increase in gravitoinertial force (1.09 $\underline{g}$), the amount of eye roll is comparable to that measured under static conditions. Above this tilt angle a discrepancy between the results of the static and dynamic modes begins to appear and to wax in direct relation to the angle of tilt; at the maximum tilt angle (63°) the dynamic, unlike the static response, shows no sign of reaching or approaching a plateau.

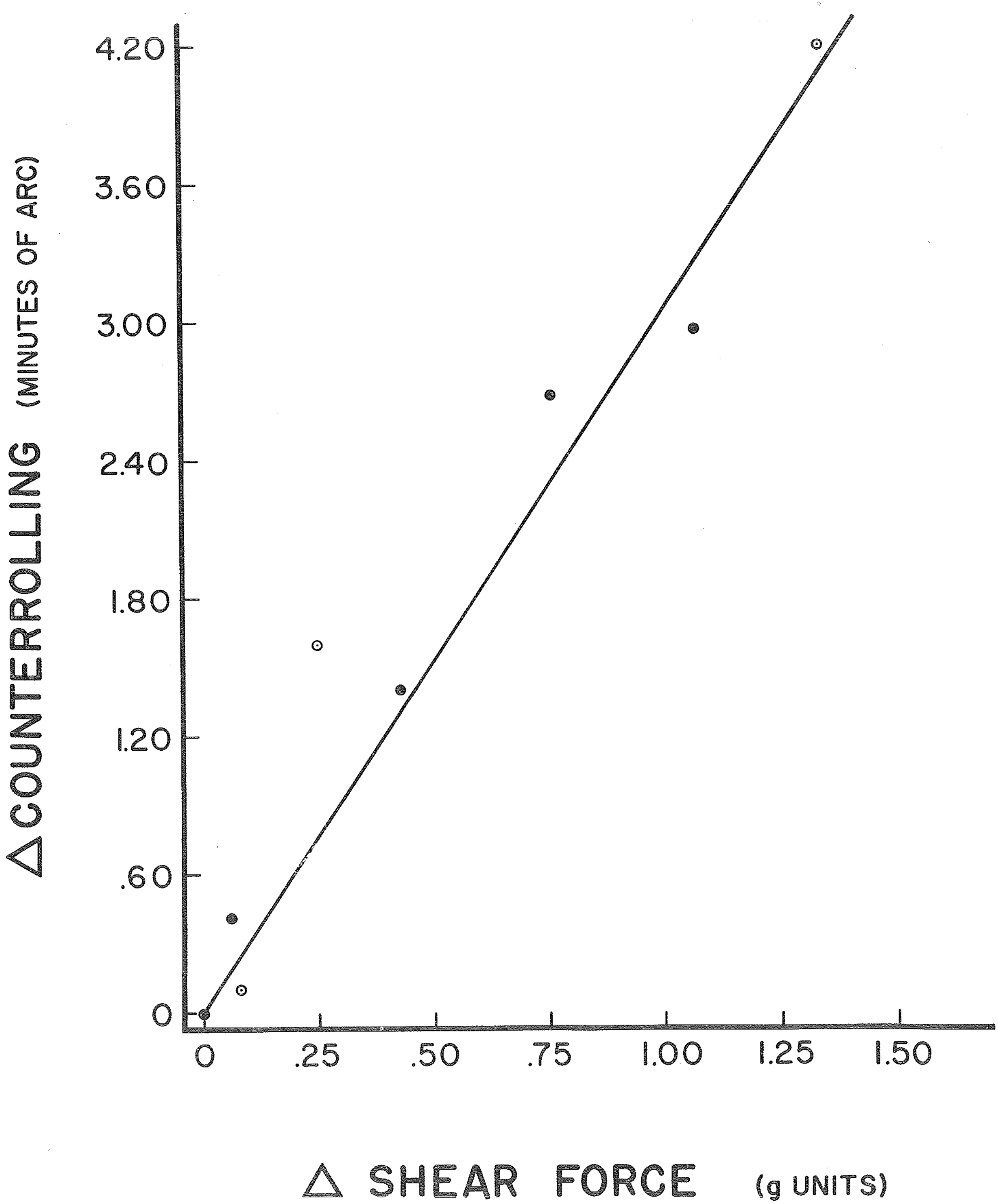

Figure 2

Average Change in Counterrolling for Normal Subjects as a Function of the Change in Shear Force. Data from Present Study Coded as Solid Circles, Those of Woellner and Graybiel (16), Recalculated for This Format, as Dotted Circles

Individually, as well as a group, the subjects with severe labyrinthine defects revealed no essential change in their small, but definite basic counterrolling response with increased g-loading. These results confirm those of Woellner and Graybiel (16) and indicate that, whereas the eye roll of a normal subject is dependent upon and limited, within the range tested, by the strength of the inertial force stimulus, that of individuals with labyrinthine defects will be dictated either by the extent of functional loss of his otolithic organs or by the contribution of nonotolithic gravireceptor systems. Evidence that this response is gravity dependent is provided by data which show changes in the amount of counterrolling found under 1-g conditions as a function of tilt, as well as by the findings of a previous study which revealed that the small amounts of ocular counterrolling manifested by such individuals was reduced or essentially eliminated when gravity was counteracted partially or completely by Keplerian flight (15). The innervation source of such small amounts of counterrolling, however, remains in question.

Differentiation of whether a residuum of otolithic function exists or whether non-otolithic gravireceptor activity can account for reduced amounts of counterrolling may depend upon the independent but complementary studies of this reflex with a subject immersed in water or exposed to centrifugation. Water immersion is highly effective in reducing, if not eliminating, the influence of the nonotolithic gravireceptor systems upon the perception of the oculogravic illusion (3), but it remains to be shown that this environment would influence ocular counterrolling. If water immersion is effective, then the question of origin of the counterrolling reflex is immediately solved. If not, centrifugation could be used in an attempt to drive this low-level function and to explore the possibility that it represents a physiologically normal variation in this response characteristic.

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13. ABSTRACT

The effect in terms of magnitude of ocular counterrolling of g-loading at various angles of tilt up to 63° was measured on normal subjects and compared with the effect upon persons with severe or complete loss of otolith function. The group of six normal subjects manifested a compensatory eye roll which increased as a direct and essentially linear function of the component of the gravitoinertial force acting laterally upon the subject. This increase in response was not observed in the five deaf subjects with severe or complete bilateral loss of their vestibular organs. These findings confirmed similar results found by other authors using other measuring techniques which show that the reflex eye movement is dependent upon and limited to the magnitude of the gravitoinertial stimulus (within the range used) when the otolitho-ocular system is functioning normally. However, when this function is impaired or lost, the magnitude of the compensatory eye roll is limited to that manifested at 1 g and possibly to non-otolithic contributions. These findings offer means for differentiation between otolithic defective individuals and "normal" persons who exhibit little counterrolling.

14. KEY WORDS	LINK A		LINK B		LINK C	
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Ocular counterrolling						
Eye movement						
Labyrinthine defects						
g-loading						